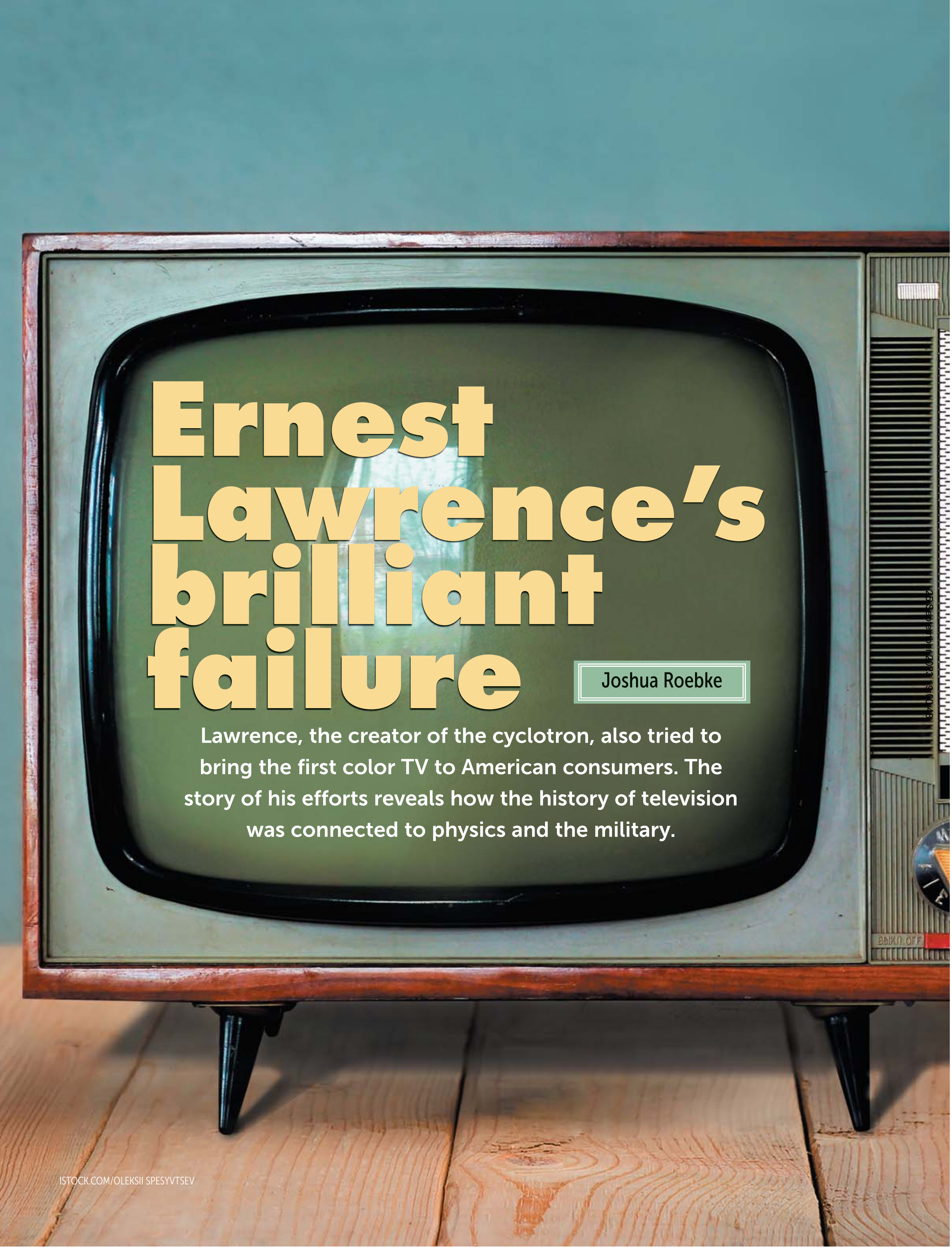
Ernest Lawrence’s brilliant failure FREE

Lawrence, the creator of the cyclotron, also tried to bring the first color TV to American consumers. The story of his efforts reveals how the history of television was connected to physics and the military.

Joshua Roebke

Physics Today **72** (3), 32–39 (2019);
https://doi.org/10.1063/PT.3.4162



Ernest Lawrence's brilliant failure

Joshua Roebke

Lawrence, the creator of the cyclotron, also tried to bring the first color TV to American consumers. The story of his efforts reveals how the history of television was connected to physics and the military.

ISTOCK.COM/OLEKSII SPESYVTSEV

Joshua Roebke is an author and researcher who also teaches at the University of Texas at Austin. His book *The Invisible World: The Story of Particle Physics and the Forces That Shaped the 20th Century* won a Whiting Foundation Creative Nonfiction Grant in 2016 and is forthcoming from Farrar, Straus and Giroux.

There are more television sets in the United States than there are people. Three-quarters of American households include a personal computer or tablet, more than those with either a cat or a dog. And nearly two-thirds of all Americans—yes, counting children—now own a smartphone. Screens are the windows through which we look at the world; they are the glassware through which we work, communicate, and play.

Just 60 years ago, however, it was barely possible to transmit color images to electronic screens. For two decades after World War II, companies spent hundreds of millions of dollars trying to display moving images in living color. Their brilliant failure only began to fade during the 1960s because of the gradual refinement of vacuum tubes and electronics. Some of the best tubes originated from an unexpected source: Ernest Lawrence (see figure 1) and other physicists from the Radiation Laboratory at the University of California, Berkeley.

Physicists largely remember Lawrence for his development of the cyclotron, which earned him the Nobel Prize in Physics in 1939. Historians typically recognize him for another activity that made him infamous: his advocacy for nuclear weapons. The labs that he established in California to support both endeavors are still named after him today: Lawrence Berkeley and Lawrence Livermore National Laboratories. But Lawrence believed that he would always be remembered for a third pursuit—the development of color television. He even feared that it would be all that he was remembered for.

In 1948, when his subordinates at the Radiation Laboratory began to construct the Bevatron, the largest accelerator at that time, Lawrence had already begun to direct his energy elsewhere. He dedicated himself to his other, dueling passions: hydrogen bombs and color televisions. His devotion to the first was attributed to patriotism, and his interest in the second was dismissed as a hobby, but it was not so easy to disentangle his motives. Color screens could display more than variety shows and evening news; they could highlight foreign rockets and incoming bombers. His work on color television also bespoke his patriotism, and, as with atomic weapons, it was an outgrowth of his physics.

Television sets used to be particle accelerators. Electromagnetic fields propelled beams of charged particles across vacuum tubes and toward their intended targets, the color phosphors on glass screens. Families gawked at the light radiating from such collisions, much as physicists scanned the images of scattering events hoping for discoveries. The physics of beams applied equally well to the electrons that transmitted sitcoms and to those that revealed the existence of quarks.

Physicists readily adapted their expertise to improving broadcasts and sets. Lawrence even founded a television company that employed dozens of physicists, including two future Nobel laureates—Luis Alvarez and Edwin McMillan. The history of color television was thus rooted in Lawrence's physics and his fears throughout the early Cold War.

Black and white to color

At the end of World War II, there were 3000 televisions in the continental US, and the images they displayed, as in most photographs and theaters, were wan and black and white. Three years later US companies were producing nearly a million televisions a year. The growth in television happened so fast that the Federal Communications Commission (FCC) stopped issuing station licenses so as not to exhaust the bandwidth.

Senator Edwin Johnson (D-CO) wanted a physicist to compel the FCC to increase its bandwidth and permit the manufacture of color sets. So in May 1949 he instructed Edward Condon, the director of the National Bureau of Standards, to investigate ultra-

FIGURE 1. ERNEST LAWRENCE at the controls of his cyclotron in the late 1930s. (Courtesy of Berkeley Lab. © 2010 The Regents of the University of California, Lawrence Berkeley National Laboratory.)

high-frequency broadcasts and a standard for color television. Six days later, the FCC invited three companies—RCA, CBS, and Color Television—to demonstrate color prototypes. Lawrence rushed to compete with them.

The story that Lawrence later told journalists about the origin of his television company, like most creation stories in business, was either an exaggeration or a lie. His interest was not piqued one Christmas morning when his children asked why their television set glared in black and white yet the world shone in color. And he did not jot down his first ideas on wrapping paper.

In the spring of 1948, George Everson, the director of personnel at Lawrence's Radiation Laboratory, introduced his boss to Philo Farnsworth, a television pioneer and the subject of a biography that Everson was writing. Lawrence had once designed a black-and-white television before Farnsworth's model superseded it. Lawrence was thinking of trying again, in color, so he conferred with Farnsworth and a few knowledgeable colleagues in Berkeley. Alvarez, for one, was already a popular consultant on television technology because of his innovations to radar systems during the war.

Later that spring Lawrence traveled to Mexico with Seeley Mudd, a notable physician and philanthropist. Aboard his private plane, Mudd told Lawrence that the head of engineering at Color Television, George Sleeper, was developing electronic screens that would display in either black and white or color.

After he returned from Mexico, Lawrence was driving south along California's coastal highway to his summer house on Balboa Island, and he had an idea. He imagined a television in which charged wires deflected a beam of electrons to fluorescent compounds on a glass screen. Earlier that spring, Lawrence had begun taking notes in a ledger to revolutionize the cyclotron. But his beloved accelerator had already been surpassed by the designs of Alvarez and McMillan. So Lawrence jotted down his television idea and dedicated his ledger instead to revolutionizing color screens.

When Lawrence returned to the Bay Area, he visited the law offices of Lippincott & Smith. Donald Lippincott represented Alvarez and Farnsworth and was preparing to file the patent on Sleeper's color television, so Lawrence met with the other partner, Samuel Smith. Smith warned that RCA had already patented a tube like the one that Lawrence imagined. The next day, Lawrence designed a pair of glasses with a rotating color wheel for watching TV. But Peter Goldmark, who had just introduced LP records, was already installing such wheels inside televisions for CBS.

Lawrence asked Alvarez to help devise an original idea. In San Francisco, they witnessed Sleeper's working set and, a day or two later, Sleeper's lawyer showed them its pending patent. The next day Lawrence sketched a new television tube, with color phosphors arrayed much like Sleeper's. Lawrence then did what he had done with the cyclotron; he directed two young men from his laboratory—Dick Mack and William Ross Aiken—to build a working device.

Other designs

Motion pictures were once successions of photographs—moments in time recorded on frames of film. Projectors advanced static frames in synchrony with the original recording and shined a light through them onto a screen. Our brains then set those frames in motion.

Television cameras minced images. They scanned what was in front of them—side to side, top to bottom—and converted the intensity of light into electronic signals. The signals were then transmitted serially as radio waves to sets. The procedure was complex, so the television was not developed until decades after the cinema. And color only compounded the problem. The electronic signal was multiplied by three, once for each of the primary colors—red, blue, and green.

There is no single way to parse visual information, so each company did it differently. RCA divided images into dots. Color Television cut them into lines. CBS projected whole images through mechanical color wheels. The different systems, however, were incompatible; the signal from one could not be displayed on the set of another.

So while his assistants were struggling to realize a prototype in 1949, Lawrence worked toward a better way to encode signals and compress information that would comply with every system. Lippincott told Lawrence that the idea was timely and shrewd.[1] If he could build a working set that displayed the signal from any system, his television would be competitive, whatever standard the FCC approved later in the year.

FIGURE 2. THE PARAMOUNT LOGO in the early 1950s included a lightning bolt to symbolize the company's interest in television. (Courtesy of the Corporate Reports Collection, Baker Library, Harvard University.)

Near the end of that summer, the Soviet Union detonated an atomic bomb. Three days later, the FCC hearings on color television proceeded at the urging of Johnson, who would also advise President Harry S. Truman on a super bomb. Lawrence and Alvarez brooded over hydrogen bombs while fretting over color television. In October they flew to Washington, DC, and lobbied the Atomic Energy Commission (AEC) to construct an enormous linear accelerator that could make uranium isotopes and tritium for bombs. Lawrence and Alvarez returned to Berkeley without any support, but they proceeded with their plans anyway.[2]

That fall, Lawrence purchased a third house, in Diablo, California. His family did not like its isolation, so Lawrence invited his colleagues over. They futzed around on color televisions and talked about super bombs inside the two-car garage.

On 28 October 1949, the FCC postponed its decision on a color standard until the coming year. But it stipulated that every color set should display black-and-white signals too. That same day scientists convened in Washington, DC, to advise the AEC about a hydrogen bomb. Alvarez was in the city consulting at the FCC television hearings, and he also showed up to lobby J. Robert Oppenheimer, chair of the AEC's General Advisory Committee, for the linear accelerator.

In business

In January 1950 Lawrence requested $7 million from the AEC to build a prototype for his giant Materials Testing Accelerator, also called the Mark I, on a former military base in Livermore. Two days later he struck a deal with the two young men refining his television. On the counsel of lawyer and businessman Rowan Gaither, Mack and Aiken should receive a third of all profits from Lawrence's color tube.

During the war Gaither had acted as a liaison between the physicists who designed radars and the companies that produced them. He was assuming that role again. In January 1950 Gaither and Lawrence established Gaither & Company, which invested the counselor's money in the physicist's devices. As the hearings on color television resumed in Washington, DC, a month later, the two men founded a second company, Telecolor.

Lawrence's color television prototype was still crude, but so were all the others. RCA's system had fragile mirrors. CBS's mechanical wheel was incompatible with black-and-white signals. Sleeper's set flickered so much that it was impossible to watch. Lawrence knew he could compete. So as the FCC hearings progressed, he renegotiated with his associates. He now agreed to pay them half of any future profits, but only up to $20 000 (roughly $200 000 today). Lawrence already knew that his idea was worth much more. Less than a week later, he filed for patents on a color television that displayed broadcasts from any other system—with phosphors deposited on metal strips, like venetian blinds, behind the screen.

The day after the filing, Gaither advised Richard Hodgson, the director of television development at Paramount Pictures, that he should meet Lawrence. The protracted struggle between cinema and television had only just begun. In 1948, the Supreme Court ended the studio monopoly in Hollywood and ordered Paramount to divest itself of theaters. So Paramount had invested in its competing technologies and became a media conglomerate. Now, it might invest in Lawrence. He and Hodgson even had something in common: Before Hodgson began developing televisions for a movie studio, he had worked on radar and managed physicists at Brookhaven National Laboratory.

Lawrence and Paramount struck a deal. Barney Balaban, Paramount's president, bought a half stake in Telecolor for $1 million and changed the name to Chromatic Television Laboratories. Hodgson became the president. Lawrence and Gaither joined the board. Alvarez, McMillan, and other physicists became consultants. Paramount even added a flash of lightning to its logo to represent its interest in electronics and Chromatic (see figure 2).

Lawrence immediately spent Paramount's money to equip his garage in Diablo. The location was convenient to his other responsibilities; Diablo was halfway between Berkeley and Livermore, where his accelerators were under construction. Lawrence even made labels to distinguish the instruments owned by Paramount from those he brought from his other labs. He then bought a Ping-Pong table and a fridge, which he stocked with beer, so everyone could have some fun at their third jobs.

Innovation and regulation

During the summer of 1950, the Korean War imposed on their plans. Lawrence and his colleagues were already busy constructing two accelerators with public funds, but they still wanted to compete with private television companies during wartime. Chromatic issued a press release asking the FCC to delay the color standard.

The FCC did not. That fall the regulator established CBS's mechanical system as the national standard. The FCC had ignored Condon's report, which praised Lawrence's idea, and voted against its own stipulation to preserve black-and-white broadcasts. After the decision, however, a federal court issued a stay on manufacturing color televisions, so as not to divert material from the war. RCA then sued for a better standard. The company had just developed a tube in which three beams passed through tiny holes in a metal plate called a shadow mask, resulting in a sharper image. RCA maintained that the federal regulator had backed a mechanical system unbefitting the electronic age.

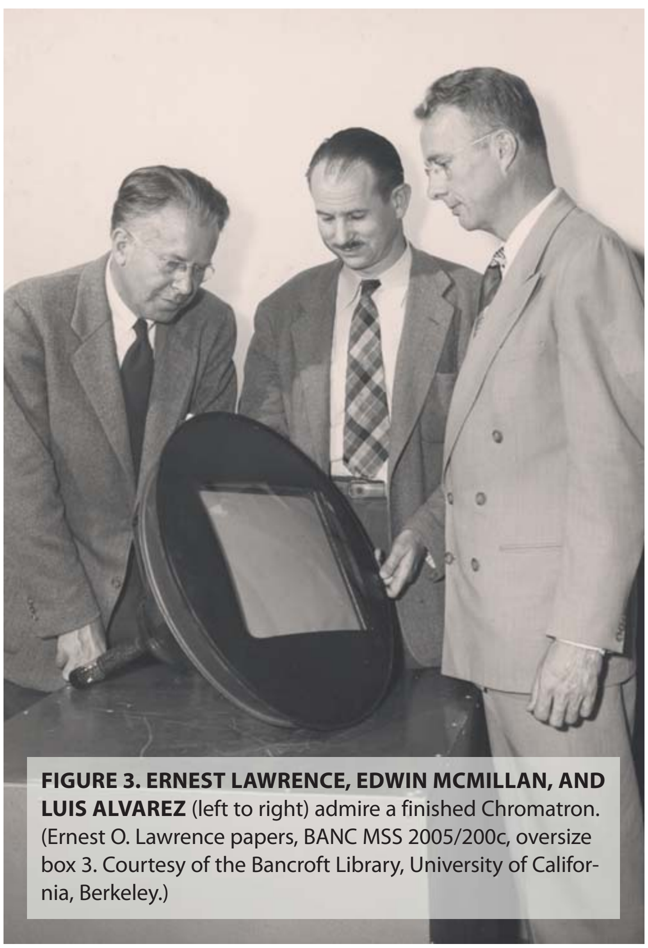


FIGURE 3. ERNEST LAWRENCE, EDWIN MCMILLAN, AND LUIS ALVAREZ (left to right) admire a finished Chromatron. (Ernest O. Lawrence papers, BANC MSS 2005/200c, oversize box 3. Courtesy of the Bancroft Library, University of California, Berkeley.)

On the day the FCC announced its standard, Gaither informed Alvarez that "the latest model of the pump-connected tube has just arrived at Chromatic. If it performs well, we may issue a press release tonight or tomorrow."[3] Lawrence was so optimistic that he was already seeking manufacturers to license the tube. But it failed so decisively that Alvarez designed a mechanical set to comply with the seemingly inevitable standard.

Within a week, however, Lawrence told Hodgson that he had a new idea, a metal grid that Alvarez and McMillan thought was promising. He was going to try it out in his garage at Diablo.[4] When Alvarez had struggled to focus the beam inside his linear accelerator, he inserted a grid of wires. Lawrence and his technician, James Vale, fashioned a comb of charged wires that similarly focused electrons and then accelerated them. RCA's shadow mask focused its beams, but it absorbed so many electrons that the picture was dull. And RCA's tube had three electron guns; Lawrence's contained one.

From the point of view of physicists, Lawrence's design was elegant. Years later, McMillan even testified that the principles behind it and his accelerator were the same. McMillan built only one synchrotron, however; Chromatic wanted to make millions of television sets.

Lawrence's innovation—bands of wires that acted as a lens and a prod for electrons—was nearly impossible to mass-produce. It had to be woven by hand like fine cloth and its specifications were beyond the capabilities of any manufacturers. Still, Balaban fibbed to the stockholders of Paramount, "I can now report that Chromatic has produced practical color television tubes. These tubes also appear to have considerable value for military purposes."[5]

The Supreme Court upheld the FCC's mechanical standard in 1951, and color broadcasts were scheduled to start that June. But CBS could not make a screen larger than 12 inches, and its picture was still jerky. No one would buy one, so CBS executives tried to purchase the rights to Lawrence's tube. Chromatic instead joined RCA to compel the FCC to adopt an electronic standard.

Lawrence and his colleagues continued tinkering with their tube. After months of frustration and broken glass, they silk-screened phosphors onto a Lucite window and bolted it to a metal set. A loud vacuum pump ran continuously to clear the air inside. Nothing was audible over the pump, and the screen was plastic, but Lawrence and his colleagues had a viable prototype.

On 19 September 1951, Lawrence demonstrated his television and its hand-woven grid at Paramount's headquarters in New York City. Journalist William Laurence glowingly reported in the *New York Times* that the tube "reproduces colors with a lifelike fidelity without any apparent fuzziness." Lawrence primarily touted its application to national defense, as he did his accelerators.

Within weeks, Lawrence had patented an improved grid with steel wires threaded through holes in a supporting frame.

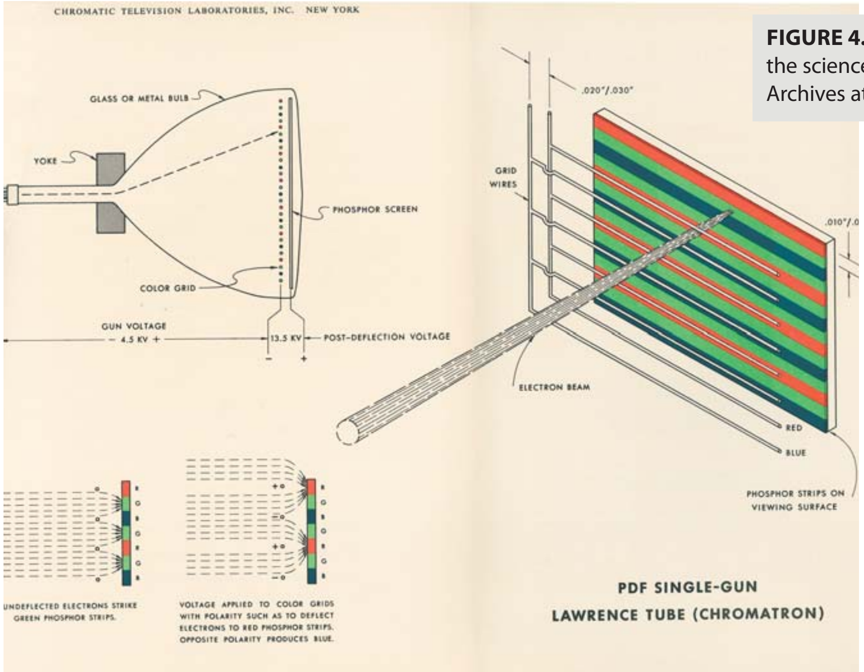


FIGURE 4. A BROCHURE FOR THE CHROMATRON emphasized the science behind the television. (Courtesy of the National Archives at San Francisco.)

Vale wove a ceramic thread perpendicular to those wires to dampen vibrations that defocused the beam. Chromatic purchased a building in Oakland to be its West Coast development lab, and trucks carrying steel and glass arrived daily. Lawrence and his associates felt the pressure of Paramount's investment. Don Gow, one of Lawrence's technicians, later said that Chromatic had underestimated the costs. The employees were used to working in a federally funded lab, not running a business.[6]

Chromatic and its competitors had even bigger problems. In October 1951, the National Production Authority ordered companies to cease producing color televisions again to prevent engineers and scarce materials from being diverted from military priorities. Companies were allowed to continue R&D, as long as federal contracts were not delayed.

Lawrence did not let regulation interfere with business. He had already postponed the Bevatron to complete the Mark I, which was also delayed and over budget, yet Lawrence designed color televisions unabated. That fall, McMillan received the Nobel Prize in Chemistry. Chromatic became the first company in the US, and the second in the world, to employ two Nobel laureates. Chromatic exploited its prestige and Lawrence's connections to promote an electronic standard.

In 1952 the *Wall Street Journal* reported that "Chromatic has made a vigorous assault on the ban." During meetings that Chromatic facilitated between regulators and television companies, CBS, RCA, and Chromatic argued for rescinding the halt order. CBS even decided that its mechanical system was inadequate, and the company announced that it too would support abandoning the mechanical standard for an electronic one.

That summer Lawrence sold his house in Diablo and moved his business out of the garage. From Oakland, he and his colleagues continued to string grids, now using nuts and saddles like those in a guitar. Paramount demonstrated Lawrence's latest tube, which had a 22-inch screen. "About the only criticism was that the colors tended to be too 'deep'," the *Wall Street Journal* reported on 23 December. Lawrence named his tube the Chromatron, in remembrance of his beloved cyclotron (see figure 3).

Fade to color

In January 1953, Lawrence traveled around the world with his family and met film stars on location. While he was away, Representative Charles Wolverton (R-NJ) scheduled hearings to determine the status of color television. "When," the representative asked, "will color television become a reality in the homes of the American people?"[7]

Lawrence sent his regrets from the Mediterranean, so Hodgson read a statement. Chromatic was producing dozens of tubes every day that could display any broadcast. "We are not talking about a gleam in some scientist's eye, or a blueprint design, or just a laboratory model," he testified. "We are referring to fully developed picture tubes that have been demonstrated successfully."[8] To prove the claim, Chromatic broadcast the coronation of Queen Elizabeth II to sick children in a London hospital that June.

The FCC agreed to reconsider its standard. RCA submitted a 700-page petition for an electronic system that it had spent $40 million to design. Paramount Pictures had its own financial worries. The company had just introduced widescreen and 3D films, and it had purchased the Warner Brothers lot on Sunset Boulevard in Los Angeles for its investments in electronics. Paramount wanted a return.

Chromatic produced a full-color brochure that included biographies of its physicists to sell television tubes based on their reputations (see figure 4). That November Crosley Radio and Television became the first company to license the Chromatron. Although retailers had begged the FCC not to announce a new color standard before the holidays, on 18 December 1953, the regulator approved RCA's electronic system. The era of color television officially began.[9]

Lawrence and his colleagues pressed to ready their tube in Oakland. They filed patents for different crosshatches of wires and leased a production plant in nearby Emeryville. They met there every Saturday to review their progress. Alvarez said, "This operation, which spent money extravagantly, resembled a downtown branch of the Radiation Laboratory."[10] That winter Chromatic signed its first production contract, to deliver green-and-orange radar screens to the US Navy.

For much of 1954, newspapers reported on the competition for television primacy among RCA, CBS, and Chromatic. The last claimed that its color sets would have the largest screens and retail for $500. RCA lowered its price and claimed that Chromatrons emitted radiation, so consumers might fear its science rather than buy it.

Yet Chromatic and its licensees still struggled to manufacture their accelerating grid. And as Hodgson admitted, "One out of twenty [tubes] might be satisfactory and the others would implode."[11] Even still, RCA manufactured only 50 000 color televisions before 1955, a quarter of the company's goal. Its sets also had to be wired by hand, and its phosphors were uniquely aligned with each shadow mask.

Exodus

In 1954, while Alvarez was the vice president of Chromatic, he asked his young colleagues at the Radiation Lab to build a tiny bubble chamber filled with liquid hydrogen to record the scattering of charged particles. He then proposed building one that was six feet wide. He wanted to make a large detector for the Bevatron rather than mass-produce small ones for others. In designing the bubble chamber, however, Alvarez realized it would capture too much data. Physicists would have to scan thousands of images or automate their discoveries. Lawrence helped Alvarez secure $1 million to develop the hardware and software to identify particles on screens. The computer revolution arrived in Berkeley before it emerged across the San Francisco Bay.

On 6 February 1956, a story on the front page of the *Wall Street Journal* called the Chromatron "tantalizing." Meanwhile, Lawrence was still filling his ledger with ideas. On 4 March, he wrote in his notebook that the color and brightness of his latest prototype were so good that it might be even better than RCA's set.[12]

Within weeks, however, Chromatic unraveled. Craig Nunan, the director of research, abruptly quit. He and three other engineers had been poached by Varian Associates, which was founded by physicists at Stanford University. Varian also produced vacuum tubes for televisions and accelerators, and it was the first company in Stanford Industrial Park. Hodgson, the president of Chromatic, then announced that he was leaving. A year later he wrote the check that founded Fairchild Semiconductor, which also moved into Stanford Industrial Park. That company produced the silicon chips that gave Silicon Valley its name.

Lawrence now sought a deal that would sever his ties to Chromatic.[6] On 1 January 1957, Litton Industries purchased Chromatic's production plant in Oakland to manufacture radar screens. Alvarez wrote to a friend that Litton had also bought the company's physicists as part of a package deal.[13] Alvarez resigned from Chromatic when he was appointed to the board of Hewlett Packard, which had also moved out of a garage and into Stanford Industrial Park.

In mid January, Paramount finally bought Lawrence and Gaither's remaining interest for $160 000. Chromatic's laboratory in the Paramount Building became the headquarters of a new subsidiary, Autometric, which developed "rapid automatic methods of handling masses of complex and conflicting information and reducing them to a decision."[14] Autometric did for spies what Alvarez did for particle physicists.

In the summer of 1958, Lawrence was in Geneva to negotiate a nuclear-test-ban treaty when he became ill. Five days after President Eisenhower announced the moratorium, Lawrence died. Gaither delivered the eulogy for his partner. A year later he cofounded Draper, Gaither, and Anderson—the first venture capital firm in Silicon Valley.

Foreign success

In 1961 Masaru Ibuka and Akio Morita, the founders and chief executives of the Sony Corp, witnessed a demonstration of Lawrence's tube at a trade show in New York.[15] The next day, Morita negotiated a license with Paramount; Japan was the only other country in the world with color programming, but there were only about 1000 RCA sets in the country. Senri Miyaoka, a physicist, traveled to New York to retrieve the Chromatron from Autometric.

Sony demonstrated its first color television in Tokyo in 1964. The company boasted that it had significantly improved an American technology, but it had as much trouble with mass production as the Berkeley physicists. The following year, Sony released its first Chromatron television, with three electron guns instead of one so it would not have to divide a single beam into three. The sets were priced at less than half the cost to make one so the company could compete with RCA. Sony would only sell 18 000 of them despite a lifetime guarantee. Morita announced that his company would not introduce the Chromatron to the US market anytime soon. One company tried; Fairchild Semiconductor licensed the tube from Paramount but failed in mass production too.

Sony was on the verge of bankruptcy after its investment in the Chromatron. But a Sony engineer, Susumu Yoshida, recommended using a single electron gun, as in Lawrence's original design. He and Miyaoka fashioned a tube that divided the beam three times and focused it twice, through a large electronic lens and small prisms. The beams then accelerated through a grill rather than a grid. Miyaoka worked 13 hours a day, 6 days a week, until he and his colleagues had a tube that transmitted clear pictures. In 1967, Ibuka named their homespun

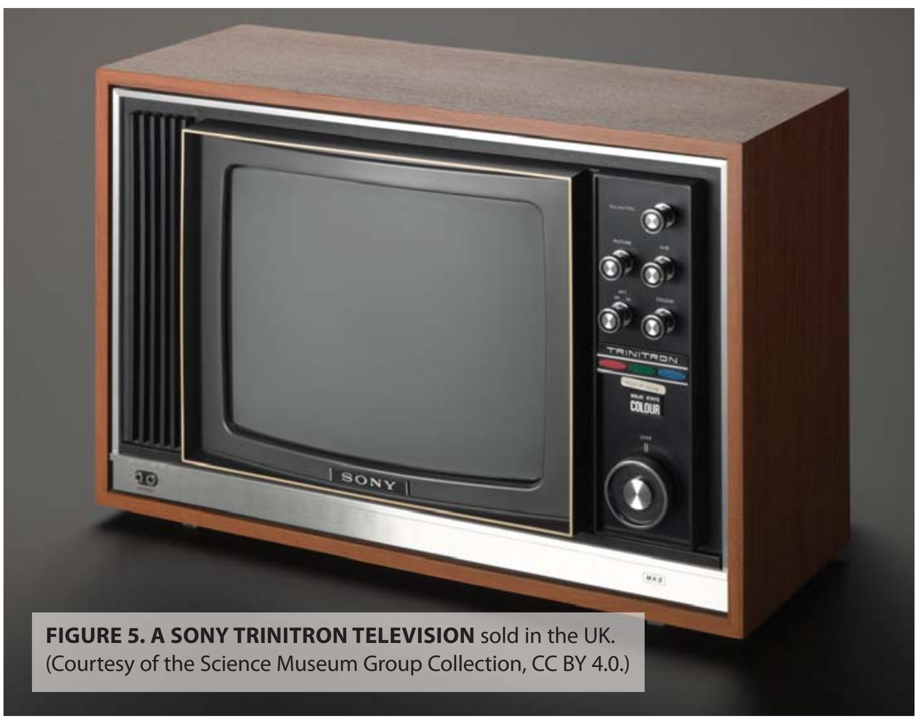


FIGURE 5. A SONY TRINITRON TELEVISION sold in the UK. (Courtesy of the Science Museum Group Collection, CC BY 4.0.)

tube the Trinitron, after its three convergent beams from a single source and its origin as the Chromatron.

The Trinitron system became the innards of the best-selling televisions in the world and the color screens that most Americans grew up with (see figure 5). By 1973 it accounted for 38% of the company's sales, and it was cited as a leading factor in the trade deficit between the US and Japan. IBM installed Trinitrons in its personal computers, and the Federal Aviation Administration used them exclusively in radars. Sony even bought its own movie studio, Columbia Pictures, and became the media conglomerate that Paramount had wanted to be.

Lawrence is barely remembered for his contribution to color television. But innovations are rarely the product of a single genius toiling in a garage. They don't even result from sound business decisions much of the time. The advent of color screens was not the product of either. No company has employed three Nobel laureates and failed as dramatically as Chromatic Television. Sony succeeded in refining its foreign technology, but only because of its stubborn persistence through near bankruptcy. The development of our ubiquitous color screens is thus a sordid tale at the intersection of government, science, academia, and business, as so many innovation stories are.

REFERENCES

1. H. Childs, Materials Assembled for a Biography of Ernest O. Lawrence, CU-369, University Archives, Bancroft Library, U. California, Berkeley.
2. G. Herken, *Brotherhood of the Bomb: The Tangled Lives and Loyalties of Robert Oppenheimer, Ernest Lawrence, and Edward Teller*, Henry Holt & Co (2002).
3. H. R. Gaither Jr to L. Alvarez (11 October 1950), RG 326, Records of the Atomic Energy Commission, National Archives at San Francisco.
4. E. Lawrence to R. Hodgson (19 October 1950), MSS 72/117c, Ernest O. Lawrence Papers ca. 1920–1968, Bancroft Library, U. California, Berkeley.
5. Paramount Pictures, *Annual Report for the Fiscal Year Ending December 30, 1950* (5 April 1951), Baker Library, Harvard U.
6. D. Gow, interview by H. Childs, Materials Assembled for a Biography of Ernest O. Lawrence, CU-369, University Archives, Bancroft Library, U. California, Berkeley.
7. C. A. Wolverton, *The Present Status of Color Television*, opening statement before the US House Committee on Interstate and Foreign Commerce, 83rd Congress, 24 March 1953, p. 1.
8. R. Hodgson, *The Present Status of Color Television*, testimony before the US House Committee on Interstate and Foreign Commerce, 83rd Congress, 26 March 1953, p. 96.
9. R. W. Burns, *The Struggle for Unity: Colour Television, the Formative Years*, Institution of Engineering and Technology (2008).
10. L. W. Alvarez, *Alvarez: Adventures of a Physicist*, Basic Books (1987), p. 166.
11. R. Hodgson, interview by R. Walker for the Silicon Genesis Project, Stanford U. Libraries (1995).
12. Lawrence's notebook, MSS 84/129c, p. 13, Lawrence papers, in ref. 4.
13. L. Alvarez to L. D. Callahan (23 January 1957), Luis W. Alvarez Papers, 1932–1988, Bancroft Library, U. California, Berkeley.
14. Paramount Pictures, *Annual Report for the Fiscal Year Ending December 28, 1957* (10 April 1958), Baker Library, Harvard U.
15. J. Nathan, *Sony: The Private Life,* Houghton Mifflin (1999).

PT